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DEVICE FOR IGNITING AN AIR-FUEL MIXTURE IN AN INTERNAL COMBUSTION ENGINE

Background Information

The present invention relates to a device for igniting an air-fuel mixture in an internal combustion engine using a high-frequency power source according to the definition of the species in the main claim.

Igniting such an air-fuel mixture using a so-called spark plug is customary in internal combustion engines for motor vehicles. In these ignition systems used today, the spark plug is inductively supplied with an adequately high voltage via an ignition coil so that an ignition spark is generated at the end of the spark plug inside the combustion chamber of the IC engine, triggering the combustion of the air-fuel mixture.

Voltages of more than thirty kilovolt may occur during operation of these conventional spark plugs, the combustion process producing residues, such as soot, oil, or carbon as well as ash from fuel and oil, which are electrically conductive under certain thermal conditions. However, at these high voltages, breakdowns must not occur at the spark plug insulator, so that the electrical resistance of the insulator should not change during the service life of the spark plug, even at the high temperatures occurring.

An ignition device in which the ignition of such an air-fuel mixture in an IC engine of a motor vehicle is performed using a coaxial line resonator is known from DE 198 52 652 A1 for example. The ignition coil is replaced here by a sufficiently powerful microwave source, a combination of a high-frequency generator and an amplifier, for example. In a geometrically

optimized coaxial line resonator, the field intensity required for the ignition comes about at the open end of the plug-like line resonator and the voltage sparkover generates an ignitable plasma link between the electrodes of the plug.

Such a high-frequency ignition is also described in the article entitled "Investigation of a Radio Frequency Plasma Ignitor for Possible Internal Combustion Engine Use" published in "SAE-Paper 970071." In this high-frequency ignition or microwave ignition, too, high voltage is generated via a low-resistance supply at the so-called hot end of a $\lambda/4$ line of an HF line resonator, without the ususal ignition coil.

Advantages of the Invention

The present invention is directed to a device for igniting an air-fuel mixture in an IC engine using a high-frequency electrical power source, having a coaxial waveguide structure into which the high-frequency electrical power may be coupled and which protrudes with one end into the combustion chamber of a cylinder of an IC engine, a microwave plasma being producible at this end due to a high voltage potential. According to the present invention, the one end of the coaxial waveguide structure is advantageously designed in such a way that, with a voltage potential present, a free-standing plasma is producible in the air-fuel mixture via a field structure protruding into the combustion chamber between the inner conductor, projecting from the waveguide structure by a predefined amount, and the outer conductor of the waveguide structure. In this free-standing plasma cloud around the end of the projecting inner conductor, no sparkover takes place between the electrodes, so that there is also no ionic current flow.

The coaxial waveguide structure is designed in such a way that, for a predefined effective wavelength λ_{eff} of the incoupled high-frequency oscillation, a line resonator is

obtained approximately according to the formula (2n+1) * $\lambda_{eff}/4$ with $n \geq 0$ and the high-frequency oscillation is coupled in, for example, via capacitive-, inductive-, mixed-, or aperture coupling. The effective wavelength λ_{eff} is essentially determined by the shaping of the end of the projecting inner conductor, by the seal of the dielectric, or by the shaping of the entire line resonator.

In the embodiment according to the present invention, the field intensity required for the ignition in the combustion chamber comes about at the open end of the resonator whose shape is largely similar to that of a spark plug. The essential advantages of such a high-frequency spark plug over the conventional use of a spark plug are most notably cost savings and weight savings due to the possibility of miniaturization. Furthermore, the heat value freedom, achieved to a large extent by the proposed device, allows a reduction in the type variety and thus cost savings as well.

The fact that an electrical measuring signal or control signal, which is a function of the physical variables of the free-standing plasma in the air-fuel mixture, may be decoupled in a simple manner preferably in the oscillator, but possibly also in other areas of the coaxial waveguide, permits adjustability of the spark size in principle, whereby, compared to the conventional spark plug, an enlarged ignition volume and easy introduction of the spark front into the combustion chamber are achievable. This results in an increase in ignition reliability, in particular in lean mix engines and in a gasoline direct injection.

Moreover, due to the possible derivation of control signals which may be decoupled, additional degrees of freedom are gained via the controllability of the spark duration. The decoupled electrical signal may be further processed in an analyzing circuit by which a system diagnosis, regulation of the high-frequency power source, and/or control of predefined

operating functions, for example, may be triggered. This controllability based on the possibility of combustion diagnostics and thus optimization of the engine control results in less wear on the structures acting as ignition electrodes and controlled burning off of contaminants, soot for example, is also possible.

If the coaxial resonator is implemented as a cylinder having a constant, circular cross section over its length, then, due to conventional sealing of the resonator's open end, or the separation of the resonator's volume from the combustion chamber, a distinct field distortion or field weakening results at one end at the tip of the inner conductor as a function of the material and the geometric design, in particular the thickness of the seal, and an increase in the power demand for reaching the necessary ignition field strength.

According to the present invention, compared to a resonator having a constant, circular cross section over its length, the power demand is distinctly reduced in an advantageous manner via suitable variation of the cross section of the coaxial resonator, i.e., possibly even below the level of a resonator without a seal.

One end of the coaxial waveguide structure in the combustion chamber is preferably provided with a seal made of dielectric material between the outer conductor and the coaxial inner conductor, the seal being provided with at least one abrupt and/or smooth cross- section change in the axial direction, resulting in an optimal field structure which enables the formation of the free-standing plasma as recited in the main claim. The plasma is formed as a free-standing cloud only at one electrode, i.e., at the end of the projecting inner conductor, and, as mentioned before, no disadvantageous spark gap is formed between two electrodes.

In particular, the seal may advantageously be placed in a recess of the outer conductor which has an abrupt cross-section enlargement toward one end. In addition, in the area of the one end, the cross sections of the inner contour of the outer conductor and the cross section of the outer contour of the inner conductor may be modified accordingly in predefined areas.

The essential advantages of this system according to the present invention are optimal separation of the resonator's volume from the combustion chamber, optionally with simultaneous sealing effect, and reduction of the high-frequency power necessary for the ignition. The concept according to the present invention is advantageously suited for retrofitting into already existing internal combustion engines.

It is possible according to a particularly advantageous embodiment that a compact ignition unit may be formed in that a free-running oscillator circuit and the coaxial waveguide are situated in a common housing; an amplifying circuit may also be placed downstream from the free-running oscillator circuit. The free-running oscillator circuit and/or the downstream amplifying circuit are/is preferably designed as an integrated semiconductor circuit using SiC of GaN components.

The essential advantage of such a compact design of a high-frequency ignition unit is in particular the possibility of size reduction, e.g., from an M14 thread size to an M10 thread size, thus achieving savings in costs and weight since the actual plug and the ignition coil are omitted. Due to physical reasons, conventional spark plugs cannot be minimized to the extent that permits novel, compact ignition systems and valve systems to be implemented in an internal combustion engine, in particular a high-compression engine. Better EMC (electromagnetic compatibility) when these components are integrated into the coaxial geometry of the device is also

achievable.

The ignition point and the spark duration may be variably set in a simple manner, in particular in combination with the above-mentioned controllability of the ignition behavior by processing a signal which may be decoupled. As mentioned above, the free-standing plasma may be positively influenced, in particular by controlling the flame size, thereby achieving increased ignition reliability in lean mixes and in gasoline direct injections.

In the design of oscillator circuits for the applications described, it must be taken into account that these are designed not only for one single operating state, because at least two basic operating states may occur, namely the ignited and the unignited state. Furthermore, the transition area between these states and additional influencing parameters, such as temperature, soot build-up, as well as other operating parameters, may have a lasting effect on the resonance behavior and the impedance behavior of the HF resonator. In conventional designs, this frequently results in only a fraction of the available power being coupled into the resonator. The remaining portion is reflected and possibly stresses or destructs the power semiconductor component used in the oscillator circuit; ignition may occasionally also be completely prevented.

According to the present invention, by using a suitable, compact free-running oscillator circuit it may be ensured in each operating state in a simple manner that a sufficient portion of the available HF power is coupled into the resonator. The use of novel high refractory semiconductor technologies, e.g. SiC or GaN, is particularly advantageous in constructing the oscillator according to the present invention in direct proximity of the engine, since these technologies are characterized by good frequency response f_T even at high temperatures, e.g. > 200°C, due to the high power density and

high integration density.

Drawing

Exemplary embodiments of the present invention are explained on the basis of the drawing.

Figure 1 shows a schematic view of a device for high-frequency ignition of an air-fuel mixture in an internal combustion engine having a coaxial waveguide structure as resonator;

Figure 2 shows a design according to the present invention of the end of the resonator protruding into the combustion chamber of the internal combustion engine and a view of the field lines of the end of the resonator protruding into the combustion chamber of the internal combustion engine; and

Figure 3 shows a block diagram of an ignition unit having a free-running oscillator, a resonator, and incoupling of the high-frequency oscillations into the resonator.

Description of the Exemplary Embodiments

Figure 1 shows a schematic view of a device for high-frequency ignition of an air-fuel mixture in an internal combustion engine having elements of what is known as a high-frequency spark plug 1. In detail, an HF generator 2 and a possibly optional amplifier 3 are present which, as a microwave source, generate the high-frequency oscillations. Inductive incoupling 4 of the high-frequency oscillations into a coaxial waveguide structure constructed as $\lambda_{eff}/4$ resonator 5 is schematically shown as an essential element of high-frequency spark plug 1.

Coaxial resonator 5 is made up of an outer conductor 6 and an

inner conductor 7, one so-called open or hot end 8 of resonator 5 together with inner conductor 7 causing the ignition, in this case as igniter 7a insulated from outer conductor 6. The other cold end 9 of resonator 5, distanced from the combustion chamber, represents a short circuit for the high-frequency oscillations. Dielectric 10 between outer waveguide 6 and an inner conductor 7 is essentially composed of air or of a suitable non-conductive material. A seal 11 is present solely for sealing open end 8 of resonator 5 from the combustion chamber. Seal 11 is made of a non-conductive material, ceramic for example, which withstands the temperatures in the combustion chamber. The dielectric properties of filling material 10 and/or seal 11 determine the dimensions of resonator 5.

The principle of field superelevation in a coaxial resonator 5 having the length (2n+1) * $\lambda_{eff}/4$ with $n \geq 0$ is used in this high-frequency spark plug 1. The high-frequency signal, which is generated by a sufficiently powerful microwave source as generator 2 and possibly amplifier 3, is fed into resonator 5 via incoupling 4, e.g., inductively, capacitively, a mixture of both, or via an aperture coupling. Due to the formation of a voltage node at short circuit 9 and a voltage antinode at an open end 8, a field resonance appears at igniter 7a, resulting in the free-standing plasma mentioned in the preamble of the description.

The essential elements of the present invention may be learned from Figure 2. For compensating the effects of field distortion or field weakening at the tip of inner conductor 7 or igniter 7a caused by seal 11 of open end 8 according to Figure 1, the cross section of a seal 20 according to Figure 2 is varied in the area of open end 8 of resonator 5. This takes place, for example, via abrupt cross-section changes 21, or also via smooth changes, tapering, or the like. For example, the cross section of the inner contour of outer conductor 6 and the cross section of the outer contour of inner conductor

7, 7a may be appropriately varied in predefined areas.

The detailed geometric dimensions of the one end 8 of resonator 5 are determined as a function of the system parameters and the material parameters of the entire device. Field lines 22 are additionally indicated in Figure 2 for the purpose of showing how an optimal geometric design of seal 20 results in a field line distribution which optimally makes a free-standing plasma possible according to the present invention.

Figure 3 shows essential elements of a high-frequency ignition unit 30 in a block diagram. In detail, this includes an HF ignition unit 31 as was described on the basis of Figures 1 and 2. Furthermore, a frequency-determining, free-running oscillator 32 using power transistors based upon refractory HF semiconductor technologies, e.g., refractory SiC or GaN components, and incoupling 33 for the HF oscillations of oscillator 32 into ignition unit 31 are present. Operation-related fluctuations in the frequency may be taken into account by using a suitable construction of oscillator 32, which is essentially known.